Reaction Time to Light as Conditioned by Wave Length and Intensity

Joseph Lawrence Holmes, A.M.

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Submitted in Partial Fulfilment of the Requirements
for the degree of Doctor of Philosophy,
in the Faculty of Philosophy,
Columbia University

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1. Introduction

The experiments reported here were made to determine the relation between the time of reaction and the intensity of the light stimulus; the time of reaction and the cessation of the light stimulus, and the time of reaction and the quality of the light stimulus and the relation existing between the first two. In the investigation of the first two problems the experimenter had the advantage of working deductively, these problems having been investigated before. The reagents employed were men graduate students in the department of Psychology in Columbia University. All were familiar with reaction time methods and were quite thoroughly practiced before the actual experiments began.

The writer wishes to express his gratitude to Professors Woodworth, Hollingworth, and Poffenberger for many helpful suggestions and to Drs. Johanson, Murphy, Newhall and Cason and Mr. Ackerson and Mr. Ginsberg who served as reagents and to Mr. Nixon who gave much valuable advice in regard to the apparatus.

2. Apparatus and Method

The time of reaction was measured with the Hipp chronoscope in which a weight was substituted for the springs to balance the armature as devised by Dunlap.[1] Several times during the experiments the chronoscope was tested for accuracy with the Cattell gravity chronometer set at 200 sigma. Following are averages of ten readings with their mean variations which indicate the high degree of accuracy secured.

198.1	M.V.	.11
199.6	M.V.	1.36
200.9	M.V.	1.14
199.7	M.V.	1.1
200.2	M.V.	.48

[1] The Hipp chronoscope: Its Use and Adjustment, by A. T. Poffenberger, Jr., and J. J. B. Morgan. *Journal of Experimental Psychology*, Vol. I, No. 3.

The reagent was seated behind a screen which entirely enclosed him, extending from the floor to well above his head and effectively shutting off all light other than the illumination provided by a lamp on the table before him which cast a light of very low intensity on the screen before him, making just perceptible the place where the stimulus was to appear.

During the experiment on reaction time to colored lights the table and screen were illuminated by a 50 watt daylight lamp at the back and to the right of the reagent's head. This of course was to prevent the reagent from becoming dark adapted.

At the edge of the table was placed the head rest of an opthalmometer which secured a constant distance between the reagent's eyes and the stimulus and a constant visual angle.[2]

This distance was 58 centimeters and the stimulus was in the median line and on a level with the eyes.

At the reagent's right, on the table was placed on ordinary telegraph key with which he reacted by an upward flexion of the wrist.

In the experiments in which white light was used as the stimuli the source of light and the method of exposing the stimuli were as follows: Extending at right angles from the screen behind which the reagent was seated was a track 30 cm. wide and 407 cm. in length. On this track was a box 90 cm. high which moved on wheels. On this box at its end farthest from the screen was placed the mechanism which exposed the stimuli. This consisted of two electric coil magnets which when the current was passed through caused an armature to pull backward. From the armature extended an arm about three inches in length which was attached to the back of a front silvered mirror which was hinged at the bottom. Thus it will be seen that by allowing the current to pass through the magnets the angle of reflection of the mirror could be changed.

The source of light was a 25-watt tungsten daylight lamp in an optics box placed 40 centimeters in front and below the level of the mirror just mentioned. In the screen and on the level with the

[2] To control the amount of light striking the retina an artificial pupil was constructed and an attempt made to use it, but it had to be abandoned owing to the time and apparatus complexities involved in securing "register."

The Theory and Practice of the Artificial Pupil, by Leonard T. Troland. *Psychological Review*, Vol. XXII, No. 3.

mirror and the reagent's eyes was a hole three centimeters in diameter covered with finely sanded glass.

To expose the stimulus, then, a switch was closed, allowing the current to pass through the magnets which moved the armature, which in turn deflected the mirror and so reflected the light from the optics box into the hole in the screen. The current through the magnets was kept constant at eight volts.

Beneath the arm which connected the armature with the mirror was a small rod bent downward at each end to dip into mercury cups and supported at the middle by a pin passing through it to uprights, thus allowing it to oscillate. When the arm moved backward, deflecting the mirror, it tipped this rod, raising it so as to break the connection in one mercury cup and immediately after making it in the other. The circuit through the lower coils was broken by the reagent when he opened his key by reacting.

By means of the movable source of light it was possible to get various intensities of light by varying the distance. In the experiment with colored light as stimuli the filters to be described later were placed in a frame between the optics box and the mirror.

The experimenter was seated at a table before and to the side of the screen with the chronoscope, a voltmeter and a switch before him. The latter closed the circuit through the magnets on the exposure apparatus, causing the stimulus to appear. When this switch was opened the mirror tipped forward again, causing the stimulus to disappear. The duration of the stimulus was for the time of the reaction, the switch being opened as soon as the reagent had reacted. The armature of the exposure apparatus was well padded and the other parts lubricated to prevent any distracting sound. The chronoscope was stopped only for rewinding.

The current used was that of the university lighting system reduced by rheostats to four volts for the chronoscope circuits and eight for the exposure apparatus. In the lamp in the optics box 120 volts were used and it was in this circuit that the volt-meter was installed, enabling the experimenter to detect any appreciable change. There was a constant fluctuation of two volts from 119 to 121 and only once during the experiments was this exceeded, and then observations were discontinued until normal conditions prevailed.

The following directions were given to each subject: "The reagent will seat himself facing the table with both arms resting upon it,

the right hand at the key. He will look at the screen before him, focusing upon the hole where the stimulus appears. The experimenter will start the clock and say 'Ready.' The reagent will then press the key with the first two fingers and get ready to react, giving his attention to the stimulus (the reactions are to be sensory). After the appropriate interval the stimulus will be exposed and the reagent will react by releasing the key with an upward motion of the wrist."

The interval between the "ready" signal and the exposure of the stimulus varied from two to four seconds.[3]

The directions were the same in the experiments on cessation except that the reagent was instructed to react when the stimulus disappeared. Cessation of the stimulus was accomplished in the following manner. The exposure apparatus was tipped slightly by a screw adjustment which allowed the light to be reflected into the hole in the screen when the experimenter's switch was opened, and closing this switch of course caused the light to be reflected on the screen above the hole. The experimenter opened the switch, exposing the stimulus, gave the "ready" signal at the same time, and after the appropriate interval closed the switch causing the stimulus to cease. Thus it will be seen that the time of exposure of the stimulus was the fore-period, two to four seconds.

3. Reaction Time to Heterogeneous Light Stimuli Varying in Intensity

The relation between the time of reaction and the intensity of the stimulus has been frequently investigated, the most thorough studies having been made by Cattell and Berger[4] at Leipzig and by Froeberg[5] at Columbia.

Cattell and Berger employed visual, auditory and tactile stimuli and Froeberg visual and auditory. Since the present investigation deals only with visual stimuli the results and conclusions from experiments in this sense department only are germane to the present work.

[3] Attention and Movement in Reaction Time, by J. V. Breitwieser, Ph.D. *Archives of Psychology*, No. 18.

[4] Brain, 32, 1886.

[5] The Relation Between the Magnitude of Stimulus and the Time of Reaction, by Sven Froeberg, Ph.D. *Archives of Psychology*, No. 8.

Cattell and Berger used as stimuli a light produced by passing an electric current through a Puluj tube, varying the intensity by means of smoked glasses placed between the tube and the reagent. Eight intensities were used, their relative intensities being denoted by the numbers 1, 7, 23, 123, 315 and 1000, the last being the full intensity of the light. Two greater intensities were also used but they were not measured. In the table below the intensities are indicated by number, being arranged in order from least intense to most intense. Following are the results obtained from two reagents:

		I	II	III	IV	V	VI	VII	VIII
B	Intensity . .								
	Average . .	338	265	238	230	222	225	207	198
	M. V. . . .	26	18	16	15	15	17	18	16
C	Average . .	281	205	190	178	177	173	165	158
	M. V. . . .	30	17	16	14	15	13	16	19

Cattell and Berger's conclusion was that there is an inverse relationship between the intensity of the stimulus and the time of reaction.

Froeberg, a pupil of Cattell made a more extensive study of the relation between the magnitude of the stimulus and the time of reaction. In his experiment with different intensities he employed as stimuli daylight reflected from paper of different shades from white to black. Nine stimuli were used, their relative intensities being denoted by the following numbers: 100, 56, 25, 16, 10, 6⅔, 3⅛, 2⅙, ¾. Two series of reactions were taken with the first five of the intensities, in the first series the size of the stimulus being 48 m.m. sq. and in the second 3 m.m. sq.

The two following tables taken from Froeberg's work summarize his results. The tables show the increase in reaction time with the decrease in intensity of the stimulus. These data are quoted rather than the absolute times because they are comparable with the results obtained in the present investigation.

TABLE VII

Int.		100–56	56–25	25–16	16–10
R	Inc.	4.2	3.0	2.4	3.0
	P. E.	.44	.42	.41	.41
W	Inc.	3.9	3.1	2.5	2.6
	P. E.	.40	.40	.42	.44

Size of Stimulus 48 mm. square

TABLE VIII

	Int.	*100–56*	*56–25*	*25–16*	*16–10*	*10–6⅔*	*6⅔–3⅛*	*3⅛–2⅛*	*2⅛–¾*
R	Inc.	3.1	2.9	4.4	6.5	3.4	5.1	4.8	5.9
	P. E.	.45	.44	.46	.49	.54	.55	.56	.59
W	Inc.	2.5	4.6	2.9	1.6	3.1	5.6	−1.2	3.0
	P. E.	.33	.33	.37	.38	.96	.87	.94	.96

Size of Stimulus 3 m.m. square

Froeberg's conclusion from these results is as follows: "On examining the results so far obtained we find that the time of reaction increases as the intensity of the stimulus decreases. The increase shows some irregularities which to the writer at least, indicate that all the disturbing factors have not been eliminated. But allowing for these, the conclusion may safely be drawn that the time of reaction tends to increase arithmetically as the intensity of the stimulus decreases geometrically."[6]

The following experiment was undertaken with the above generalization in mind. Since the stimuli used by Froeberg[7] only approximated a geometrical progression it was reasoned that a test of his generalization would be the employment of an exact geometrical progression. Ten stimuli were used, the most intense being denoted in the table of results by the number I, the next in degree of intensity by the number II, etc. Stimulus number I is one and one-half times as intense as number II, and number II is one and one-half times as intense as number III, etc.

These intensities were obtained by varying the distance of the source of light from the screen in accordance with Bouguer's principle. For intensity I the source of light (the mirror) was placed at 55 cm. from the screen, for intensity II this distance was multiplied by $\sqrt{1.5}$ or 1.245 and so on for the other intensities. These differences in intensity were by successive comparison easily perceptible.

Three reagents were employed for this experiment and the following procedure was followed with the first two, M. and C. Reaction times were taken to the first five intensities on each of ten successive days and to counterbalance the effects of fatigue and practice each

[6] Op. cit.
[7] Op. cit.

succeeding series began with a different stimulus than did the series before it, the second stimulus in the first series being the first in the second series and the first in the first series being the last in the second, and so on until each stimulus had occupied each position in the series twice. Then reaction times to the second five intensities were taken in the same manner.

The results are given in Tables I, II, III and IV. Each figure in the body of the tables is the average of 25 reaction times and the figures at the bottom of the tables are the averages of 250 reaction times. The variability of the measures is indicated by the mean variation given under each average in the table and the reliability of the final averages is indicated by the probable error. This latter was calculated according to the formula: P. E. = .8453 M. V./$\sqrt{n}$.

Appended to each table is a table showing the increase in reaction time with decrease in the intensity of the stimulus. The probable error of these differences was obtained in the following manner. First the differences between the average reaction times to intensity I and intensity II were computed with regard to signs. The algebraic sum of these differences divided by the number 10 gave the average and from this was computed the variations. The sum of the variations divided by 10 gave the mean variation of the differences. Then from this was computed the probable error by the formula, P. E. = .8453 M. V./$\sqrt{n}$. The same procedure was followed with each successive column of averages.

These results seem to indicate that each time that the intensity of the stimulus is divided by one and one-half that approximately 3 sigma is added to the reaction time, as shown in table VI–B. Then the question arose as to whether or not the increase in time is proportional to the decrease in the intensity of the stimulus or in other words would a series of stimuli composed of intensities I, III, V, VII, IX show an approximate increase of 6 sigma each time. In previous investigations this question was not considered and the data threw no light on it.

The same procedure was followed with reagent J except that instead of reacting to the first five intensities and then to the second five, he reacted to the odd numbered intensities first and then to the even numbered ones. Also instead of reacting one hundred twenty-five times each day for twenty days this subject

reacted six hundred and twenty-five times on each of four days. This was done in the interest of economy of time.

The data obtained with reagent J are given in tables V and VI and seem to indicate that the difference in reaction times is to some degree proportional to the difference in intensity.

Table VI-A shows reagent J's average reaction times to each of the ten successive stimuli and the difference in time between the successive intensities.

Inspection of the table of differences, Table VI–B, shows such irregularities as the following: reagent M's difference between stimulus III and stimulus IV is 2.72 sigma, while reagent C's difference between the same two stimuli is 7.28 sigma; reagent J's difference between stimulus IV and stimulus V is 5.92 sigma, while reagent C's difference is 2.01 sigma. This would seem to indicate that some factors making for constant errors were operating in the case of each reagent. That these factors are not in the apparatus nor the procedure is indicated by the fact that the discrepancies are not found in the same place for each reagent and by the fact that the averages of the three reagents show fairly constant increases of reaction time with decreases of intensity with the possible exception of the difference between stimuli II and III.

The difference for reagent J between intensities V and VI is given in this table but no weight is to be attached to it in considering the row of averages.

The foregoing data seem to confirm the generalization that reaction time increases arithmetically (approximately) as the intensity of the stimulus decreases geometrically and furthermore the increase in reaction time seems to be to some extent proportional to the decrease in intensity.

TABLE I

Reagent M—First 5 Intensities

Series	*Intensity I Average M. V.*	*Intensity II Average M. V.*	*Intensity III Average M. V.*	*Intensity IV Average M. V.*	*Intensity V Average M. V.*
I	156.08	157.04	162.72	168.60	174.64
	10.32	7.04	4.88	8.92	6.28
II	140.72	147.28	144.48	150.44	154.52
	5.36	4.76	6.23	5.40	8.68
III	130.12	136.60	149.56	153.28	153.40
	6.92	4.92	8.56	7.16	7.36
IV	137.64	143.04	146.36	144.00	150.36
	7.68	6.44	6.76	8.00	4.84
V	133.40	137.44	146.12	145.20	150.64
	7.04	7.68	7.32	10.72	6.32
VI	134.28	144.40	156.64	156.24	156.72
	11.00	6.16	6.08	6.36	8.88
VII	142.04	138.28	146.96	150.08	156.60
	6.70	6.00	6.60	10.52	6.68
VIII	136.92	133.72	133.12	142.68	152.44
	7.56	9.76	12.12	6.16	8.80
IX	134.40	132.88	142.32	142.60	152.84
	9.36	8.40	5.75	5.44	9.88
X	134.88	143.68	151.80	154.08	149.64
	6.48	5.00	5.04	5.76	4.56
Average	137.94	141.53	148.00	150.72	155.18
M. V.	4.99	5.55	5.73	5.86	4.48
P. E.	1.33	1.48	1.52	1.56	1.19
	Difference	3.59	6.47	2.72	4.46
	P. E.	.72	.90	.58	.70

TABLE II

Reagent M—Second 5 Intensities

Series	*Intensity VI Average M. V.*	*Intensity VII Average M. V.*	*Intensity VIII Average M. V.*	*Intensity IX Average M. V.*	*Intensity X Average M. V.*
I	148.28	154.48	157.72	160.32	167.24
	5.80	5.68	5.60	6.88	4.80
II	143.60	145.28	149.00	157.00	164.00
	6.92	11.00	8.64	7.92	7.76
III	157.12	163.16	157.28	160.28	171.24
	5.72	5.12	6.20	5.56	7.20
IV	165.16	177.00	185.56	179.40	180.00
	11.28	16.56	19.28	7.76	13.80
V	173.32	165.40	161.72	166.00	179.16
	11.68	8.80	9.76	7.60	16.32
VI	150.48	150.24	155.96	157.60	162.20
	7.68	4.80	7.76	6.12	5.96
VII	147.48	150.64	153.88	155.84	158.16
	6.48	6.24	4.80	5.40	6.40
VIII	154.60	151.48	155.52	158.92	156.16
	5.40	6.08	5.00	3.80	4.96
IX	142.36	150.00	151.84	158.48	156.80
	6.44	4.08	5.16	5.72	5.64
X	146.60	154.20	153.52	159.88	153.00
	5.48	6.44	5.08	5.84	7.20
Average	152.90	156.18	158.20	161.37	164.79
M. V.	7.72	7.39	6.17	4.53	7.69
P. E.	2.06	1.97	1.64	1.20	2.05
	Difference	3.28	2.02	3.17	3.42
	P. E.	.86	.62	.46	.81

TABLE III

Reagent C—First 5 Intensities

Series	*Intensity I Average M. V.*	*Intensity II Average M. V.*	*Intensity III Average M. V.*	*Intensity IV Average M. V.*	*Intensity V Average M. V.*
I	151.08	156.20	158.72	165.08	169.80
	12.48	6.76	7.12	10.40	10.80
II	163.80	167.28	172.52	173.12	179.92
	7.52	9.32	5.88	9.80	6.20
III	159.40	166.64	170.92	177.80	173.04
	10.16	5.28	7.08	8.08	8.28
IV	165.72	157.04	159.72	174.72	181.08
	10.64	8.52	8.00	8.56	9.08
V	156.68	159.04	168.20	171.56	172.44
	10.44	6.84	7.00	6.96	10.68
VI	154.04	142.96	146.84	170.52	175.48
	6.68	7.76	7.88	13.24	7.36
VII	151.44	161.08	173.80	169.08	173.32
	7.32	7.12	8.88	6.00	7.76
VIII	147.24	159.56	159.00	161.44	162.32
	8.88	9.20	9.20	8.20	7.60
IX	160.84	151.16	162.12	173.88	170.72
	8.92	12.00	9.16	8.48	10.16
X	159.60	161.76	165.96	173.40	172.60
	8.52	9.24	11.04	8.64	8.04
Average	156.98	158.27	163.78	171.06	173.07
M. V.	4.88	5.14	6.50	3.62	3.50
P. E.	1.30	1.37	1.73	.96	.93
	Difference	1.29	5.51	7.28	2.01
	P. E.	1.57	.83	1.28	.65

TABLE IV

Reagent C—Second 5 Intensities

Series	*Intensity VI Average M. V.*	*Intensity VII Average M. V.*	*Intensity VIII Average M. V.*	*Intensity IX Average M. V.*	*Intensity X Average M. V.*
I	196.96	201.96	207.16	209.40	204.08
	9.36	9.44	13.24	12.00	19.60
II	190.00	182.60	191.04	189.48	191.76
	7.68	13.96	10.28	9.36	6.68
III	195.40	189.40	197.60	198.44	208.00
	13.60	11.52	17.32	14.64	12.64
IV	181.52	190.84	202.00	197.40	197.92
	6.92	7.00	6.88	8.96	7.88
V	189.72	208.08	214.12	208.52	204.00
	16.80	13.20	7.88	8.44	11.92
VI	193.20	202.20	192.84	197.24	213.04
	9.48	12.44	9.24	9.24	12.68
VII	185.08	182.20	186.44	189.64	192.24
	7.84	8.16	10.20	9.92	7.20
VIII	180.16	184.76	180.44	183.96	180.20
	10.96	9.56	8.68	10.80	6.44
IX	184.00	185.80	195.40	187.32	195.16
	6.16	6.40	8.56	9.48	10.24
X	189.20	185.20	171.80	185.08	177.84
	7.56	7.72	7.36	7.84	6.44
Average	188.52	191.30	193.88	194.64	196.42
M. V.	4.66	7.66	10.37	7.55	8.98
P. E.	1.24	2.04	2.76	2.01	2.39
	Difference	2.78	2.58	.76	1.78
	P. E.	1.13	1.44	1.06	1.18

TABLE V

Reagent J—Alternate Intensities

Series	*Intensity I Average M. V.*	*Intensity III Average M. V.*	*Intensity V Average M. V.*	*Intensity VII Average M. V.*	*Intensity IX Average M. V.*
I	181.44	173.60	190.32	184.52	193.60
	12.44	10.92	19.04	9.88	15.72
II	133.48	180.44	181.76	200.48	187.80
	6.64	6.76	9.80	11.76	9.60
III	158.12	170.84	173.52	176.28	192.68
	7.12	8.20	6.28	10.44	7.16
IV	156.96	172.76	189.04	176.96	189.28
	5.28	7.88	5.88	9.92	5.32
V	155.88	172.40	180.84	185.96	186.20
	7.44	9.04	6.60	7.52	7.88
VI	158.84	172.56	181.92	181.08	181.04
	10.76	7.76	6.12	7.48	10.08
VII	151.16	162.32	170.84	177.52	190.04
	10.24	8.80	8.20	8.52	11.88
VIII	157.48	172.84	175.00	179.92	189.92
	7.48	7.88	10.24	7.80	8.92
IX	144.16	173.56	188.28	184.28	195.72
	13.76	10.56	9.60	11.00	10.64
X	156.96	169.84	173.56	182.56	186.64
	7.36	6.20	6.88	6.24	6.48
Average	155.44	172.11	180.50	182.95	189.29
M. V.	7.51	2.67	5.82	4.68	3.10
P. E.	2.00	.71	1.55	1.24	.82
	Difference	16.67	8.39	2.45	6.34
	P. E.	1.88	1.23	1.30	1.46

TABLE VI

Reagent J—Alternate Intensities

Series	*Intensity II Average M. V.*	*Intensity IV Average M. V.*	*Intensity VI Average M. V.*	*Intensity VIII Average M. V.*	*Intensity X Average M. V.*
I	176.92 11.00	183.32 9.84	192.20 12.04	199.76 11.56	212.96 11.84
II	162.60 11.00	170.40 7.84	182.40 5.52	183.68 8.60	191.20 7.24
III	169.56 4.56	175.72 6.48	191.88 11.20	197.56 11.68	205.52 12.60
IV	157.52 8.60	171.80 8.80	181.52 8.04	179.16 8.48	189.00 6.32
V	163.56 11.92	174.96 7.04	177.72 9.44	185.68 8.28	197.16 7.76
VI	160.64 6.48	175.12 6.04	181.08 7.96	182.48 5.20	192.68 7.88
VII	163.72 6.40	180.32 6.56	180.72 8.80	187.00 7.84	190.28 6.84
VIII	172.20 5.56	167.52 8.64	173.16 8.88	169.96 8.32	174.96 7.60
IX	154.68 10.36	172.32 6.32	183.12 6.76	190.12 9.96	188.64 9.04
X	170.44 6.52	174.32 5.52	179.44 6.36	176.36 8.12	183.32 5.52
Average M. V. P. E.	165.18 5.67 1.51	174.38 3.30 .88	182.32 4.06 1.08	185.17 6.84 1.82	192.57 7.60 2.02
	Difference P. E.	9.40 1.21	7.74 1.00	2.85 .65	7.40 .76

TABLE VI–a

Reagent J—10 Intensives

Intensity I *I* *Average* *P. E.*	*Intensity II* *Average* *P. E.*	*Intensity III* *Average* *P. E.*	*Intensity IV* *Average* *P. E.*	*Intensity V* *Average* *P. E.*	*Intensity VI* *Average* *P. E.*	*Intensity VII* *Average* *P. E.*	*Intensity VIII* *Average* *P. E.*	*Intensity IX* *Average* *P. E.*	*Intensity X* *Average* *P. E.*
155.14	165.18	172.11	174.58	180.50	182.32	182.95	185.17	189.29	192.57
2.00	1.51	.71	.88	1.55	1.08	1.24	1.82	.82	2.02
Difference	9.74	6.93	2.47	5.92	1.82	.63	2.22	4.12	3.28
P. E.	1.48	1.74	1.08	1.14	1.1	1.69	1.92	1.05	1.69

TABLE VI–b

Averages of Differences of 3 Reagents

	Intensities I–II	*Intensities II–III*	*Intensities III–IV*	*Intensities IV–V*	*Intensities V–VI*	*Intensities VI–VII*	*Intensities VII–VIII*	*Intensities VIII–IX*	*Intensities IX–X*
Reagent M									
Difference . . .	3.59	6.47	2.72	4.46		3.28	2.02	3.17	3.42
P. E.	.72	.90	.58	.70		.86	.62	.46	.18
Reagent C									
Difference . . .	1.29	5.51	7.28	2.01		2.78	2.58	.76	1.78
P. E.	1.57	.83	1.28	.65		1.13	1.44	1.06	1.18
Reagent J									
Difference	9.47	6.93	2.47	5.92	1.82	.63	2.22	4.12	3.28
P. E.	1.48	1.74	1.08	1.14	1.1	1.69	1.92	1.05	1.69
Average	4.78	6.30	4.15	4.13		2.23	2.27	2.68	2.82

4. Reaction Time to the Cessation of Heterogeneous Light Stimuli Varying in Intensity

The only investigation of this problem reported in the literature is that made by Professor Herbert Woodrow[8] who used as stimuli three intensities of sound and two intensities of light, the latter designated as bright light and weak light. Some reactions were also taken to electric dermal stimulation and touch. In connection with the present problem his results obtained with light stimuli are pertinent. He concludes in part as follows:

1. "The experiments here reported show that the reaction time to the cessation of a sound or light stimulus is in all cases the same as the reaction time to the beginning of that stimulus. This statement includes the following corollaries: (1) The same difference between reaction times to sound and light exists in the case of reactions to their cessation as in the case of reactions to their beginning. (2) The lengthening in reaction time due to a decrease in intensity of stimulus is equal in amount and follows the same law in the case of both beginning and cessation reactions."

Five reagents were employed by Woodrow, "three of which, subjects Ww, Ht and St, were quite practiced in beginning[9] reactions before the work began, while the other two, subjects Vs and Sz, were altogether unfamiliar with work in reaction time. . . . The instructions called for a reaction which would ordinarily be regarded as a form of motor reaction."

On the following page is a part of Table IV which summarizes Woodrow's results with light stimuli.

Another investigation somewhat similar to the present one is that reported by Wells[10] who studied the reaction time to five durations of a light stimulus and to five durations of darkness preceded and followed by light of a constant intensity. In concluding he states that his results do not confirm those of Froeberg but rather indicate that the opposite is true, namely, that the longer the duration of the stimulus is, the longer the reaction time is, and vice versa, and like-

[8] Reactions to the Cessation of Stimuli and Their Nervous Mechanism, by Herbert Woodrow. The *Psychological Review*, Vol. XXII, No. 6.

[9] Reactions to the onset of the stimulus are called by Woodrow "beginning reactions."

[10] The Influence of Stimulus Duration on Reaction Time, by Geo. R. Wells. *Psychological Monographs*, Vol. XV, No. 5.

wise with the results from the observations in regard to occlusion of the light stimulus. In brief, his experiment with occlusion of the stimulus consisting in taking the reaction time when the light stimulus was momentarily shut off. Five durations of darkness were used,

TABLE IV

Mode	*Subject*		*Beginning Reactions*		*Cessation Reactions*	
			Average	*Average M. V.*	*Average*	*Average M. V.*
Light	Bright	Ww	154	16	151	16
		Ht	162	21	167	18
		St	183	21	184	19
		Vs	192	19	185	17
		Sz	201	22	201	22
	Weak	Ht	205	33	203	24
		Vs	243	26	234	21
		Sz	268	28	250	26

as follows: A1 1 sec., A2 150^{σ}, A3 66^{σ}, A4 31^{σ} and A5 10^{σ}. In the last paragraph of a several page report and under the subtitle "Conclusion" occurs the following statement:

"It should be noted that in this investigaiton the subjects completed reacting to all the stimuli of a certain duration before they reacted to the stimuli of another duration. With our apparatus it is impossible to mingle the stimuli of various durations indiscriminately." Only by mingling the stimuli so that each one occupies each position in the series is it possible to equalize practice effect and fatigue, and unless this procedure is followed any relatively small difference will be obscured by these factors.

The present experiment was done in the following manner. Reagent M, shortly after reacting to the onset of the stimuli as described previously reacted to the cessation of five intensities in different sequences until each had appeared twice in each position. The intensities employed were gotten in the same manner as in the previous experiment, but they are not exactly the same intensities, being somewhat greater, due to a slight adjustment in the apparatus

and so the results are not to be compared directly with those previously given.

The results are given in Table VII. Of the four differences found, two are in the direction of greater time as the intensity diminished and two in the direction of lesser time. The difference between IX and X is the greatest. The fact that any difference at all was found suggested that perhaps the difference was so small as to be obscured by the error of observation, and to test this hypothesis the reactions of reagent A were taken to alternate intensities.

The results from Reagent A are given in Table VIII. Here the difference is in the direction of greater time and is fairly constant as the intensity decreases.

Reagents J and N were next employed to determine the relation between reaction time to the onset and cessation of the stimulus. The results for reagent J are given in Tables IX, IX a and XI, and for reagent N in Table X. The results given in Table IX were gotten in the following manner. Using intensities V, VI and VII fifteen reactions were taken to the onset of V, fifteen to the cessation of V, then the same with VI and then with VII. This was continued until each stimulus had occupied each position in the series twice and in the succeeding series onset and cessation were alternated.

Inspection of Table IX shows that the difference in reaction time between onset and cessation is relatively large, cessation time being shorter and increases as the intensity decreases; that the differences between the onset reactions follow the law of increasing time to decreasing intensity, and that any difference between the reaction time to cessation of the different intensities is so small as to be obscured by the error of observation. To test this last statement Reagent N's reactions were taken to the alternate intensities IV, VI and VIII, the same procedure being followed except that ten reactions were taken each time instead of fifteen. Table X gives the results. Here it is also shown that the difference between onset and cessation is relatively large and increases with decreasing intensity, and that there is a difference between the succeeding cessation times that is small and fairly constant. This last is in exact agreement with the results gotten from reagent A and given in Table VIII.

Inspection of Tables I to IV inclusive, giving the results of the experiment on reaction time to white light (onset) shows that in

reacting to the second five intensities the differences were smaller than in the case of the first five. This seems to indicate that the more practiced the reagent the smaller the difference. All the reagents used have been quite thoroughly practiced. On the basis of this it was reasoned that if a relatively unpracticed reagent were employed that differences between reaction time to cessation of succeeding intensities would be found. Reagent J who was previously found to be quite regular from the beginning was employed after about six months had elapsed since last he reacted. Table XI gives the results. The differences are as expected, except that they are large. Also the differences between onset and cessation are in general in agreement with previous results.

CONCLUSION

The results of this experiment seem to indicate that reaction time to cessation of the light stimulus follows the same law as reaction time to the onset of the light stimulus, except that the arithmetical increase of the reaction time with geometrical decrease of the intensity of the stimulus is less in the former than it is in the latter; that there is a relatively large difference between reaction time to onset and cessation of the stimulus, cessation reactions being much quicker and that the lower the intensity the greater this difference.

TABLE VII

Reagent M—Cessation of 5 Intensities

Series	*Intensity VI Average M. V.*	*Intensity VII Average M. V.*	*Intensity VIII Average M. V.*	*Intensity IX Average M. V.*	*Intensity X Average M. V.*
I	131.92 7.64	131.80 4.32	127.04 8.52	133.20 6.28	140.20 10.12
II	142.88 6.80	142.64 6.48	141.48 6.40	142.40 7.28	145.12 10.20
III	150.92 7.56	152.56 7.44	143.36 5.80	143.40 8.24	157.20 6.36
IV	157.84 8.52	158.40 6.48	161.00 7.36	158.60 5.16	162.56 6.64
V	159.12 9.08	154.68 5.32	150.92 8.60	152.92 6.00	167.52 4.42
VI	150.68 7.48	154.68 9.24	151.92 8.44	146.00 9.84	155.44 6.44
VII	146.52 9.56	155.52 7.88	148.92 7.64	151.20 6.68	159.08 8.32
VIII	148.52 5.96	141.52 4.68	139.36 6.68	144.20 6.60	156.12 8.28
IX	143.56 4.08	139.84 5.48	145.84 5.72	144.80 8.88	151.04 5.64
X	154.60 6.84	151.92 5.64	153.84 5.32	153.28 7.56	159.36 9.80
Average M. V. P. E.	148.65 5.97 1.59	148.35 7.52 2.00	146.36 6.95 1.85	147.00 5.60 1.49	155.30 5.94 1.58
	Difference P. E.	−.30 .82	−1.99 .61	+.64 .45	+8.30 .87

TABLE VIII

Reagent A—Cessation of 5 Alternate Intensities

Series	*Intensity II Average M. V.*	*Intensity IV Average M. V.*	*Intensity VI Average M. V.*	*Intensity VIII Average M. V.*	*Intensity X Average M. V.*
I	140.72	134.84	136.64	138.76	146.04
	11.20	9.00	8.48	11.72	14.76
II	146.28	149.64	150.76	148.04	154.76
	12.76	12.64	14.08	9.00	9.56
III	145.96	152.28	146.00	151.52	160.68
	10.16	14.04	10.40	10.04	8.84
IV	153.68	142.68	147.80	154.24	154.32
	11.80	11.24	7.20	8.16	9.12
V	146.08	147.00	153.28	161.00	145.52
	8.56	8.48	10.68	12.96	8.76
VI	152.64	141.44	152.72	165.00	172.64
	20.16	9.08	10.08	11.28	12.24
VII	150.04	175.80	164.48	165.12	173.24
	11.56	7.68	7.84	8.12	11.20
VIII	160.48	167.32	162.84	160.48	161.24
	8.80	9.04	12.60	8.80	10.24
IX	159.12	166.24	168.44	166.00	176.20
	9.56	10.04	10.76	12.16	10.68
X	160.16	152.28	161.84	175.76	160.56
	12.40	9.80	11.00	12.00	12.56
Average	151.51	152.95	154.48	158.59	160.52
M. V.	5.70	10.10	7.93	8.36	8.28
P. E.	1.52	2.69	2.11	2.23	2.21
	Difference	1.44	1.53	4.11	1.93
	P. E.	1.94	1.07	.95	1.80

TABLE IX

Reagent J—3 Intensities

	Intensity V		*Intensity VI*		*Intensity VII*	
Series	*Onset Average M. V.*	*Cess. Average M. V.*	*Onset Average M. V.*	*Cess. Average M. V.*	*Onset Average M. V.*	*Cess. Average M. V.*
I	157.26	152.93	172.53	161.53	188.33	163.20
	7.46	8.53	10.40	15.06	19.26	7.53
II	166.33	161.06	178.66	156.60	186.66	168.93
	6.20	13.66	10.53	8.46	5.60	6.40
III	189.90	173.33	174.60	150.53	183.00	153.00
	8.13	8.73	5.13	6.66	16.53	8.80
IV	151.66	147.40	161.93	152.66	166.66	148.40
	6.53	13.33	5.73	17.60	10.66	10.40
V	166.66	154.26	168.06	154.80	171.13	147.93
	5.20	15.46	7.93	11.33	9.86	11.06
Average	166.34	157.79	171.15	155.22	179.15	156.29
M. V.	4.75	3.75	2.46	1.53	4.10	3.90
P. E.	1.77	1.39	0.91	0.57	1.52	1.45
	Difference	−8.55		−15.93		−22.86
	P. E.	.88		2.15		1.47

TABLE IX–a

Intensity V Begin Average P. E.	*Intensity VI Begin Average P. E.*	*Intensity VII Begin Average P. E.*	*Intensity V Cess. Average P. E.*	*Intensity VI Cess. Average P. E.*	*Intensity VII Cess. Average P. E.*
166.34	171.15	179.15	157.79	155.22	156.29
1.77	.91	1.52	1.39	.57	1.45
Difference	4.81	8.00		−2.57	1.07
P. E.	2.77	1.22		2.45	1.96

TABLE X

Reagent N—Onset and Cessation—Intensities IV, VI, VIII

IV		*VI*		*VIII*	
O Average M. V.	*C* Average M. V.	*O* Average M. V.	*C* Average M. V.	*O* Average M. V.	*C* Average M. V.
169.0	153.8	155.6	151.8	159.0	165.6
6.6	3.1	8.6	4.4	6.6	11.0
164.6	154.2	157.8	162.1	160.4	147.2
5.8	5.2	10.2	9.7	4.4	2.8
158.7	157.8	161.2	155.2	171.2	157.0
7.3	5.2	5.6	4.4	7.2	3.0
150.3	154.8	172.7	155.7	173.5	157.7
4.5	6.8	10.9	7.1	5.9	7.9
172.7	161.1	169.6	161.5	165.3	156.2
10.1	6.1	9.2	6.7	2.9	3.2
155.5	154.1	162.6	154.3	166.4	162.9
5.7	3.9	5.2	6.2	5.4	3.4
Av. 161.8	155.96	163.25	156.76	165.96	157.76
M. V. 6.96	2.32	5.26	3.35	4.40	4.32
P. E. 2.40	.80	1.81	1.15	1.51	1.49
O–C { Diff. 5.84		6.49		8.20	
O–C { P. E. 1.74		1.10		1.48	
O–O { Diff.	1.45		2.71		
O–O { P. E.	2.67		0.72		
C–C { Diff.		.80		1.00	
C–C { P. E.		.64		2.32	

TABLE XI

Reagent J—Onset and Cessation—Intensities V, VI, VII

V		VI		VII	
O *Average* *M. V.*	*C* *Average* *M. V.*	*O* *Average* *M. V.*	*C* *Average* *M. V.*	*O* *Average* *M. V.*	*C* *Average* *M. V.*
175.6	162.8	165.2	158.0	179.1	165.8
10.4	7.2	8.0	6.3	8.7	5.8
175.0	160.8	181.9	165.0	171.9	158.8
5.6	6.0	9.1	7.2	13.1	6.2
170.8	161.8	173.2	161.2	180.9	170.2
7.0	2.0	6.6	6.9	10.9	3.6
180.3	164.6	168.5	168.5	194.8	175.9
9.1	8.2	11.1	10.5	12.9	6.9
170.8	172.5	182.3	167.0	191.1	180.2
7.0	17.1	8.1	9.9	9.1	8.2
187.7	165.5	203.1	183.7	184.3	175.2
8.1	17.3	10.6	15.7	12.7	8.1
Av. 176.70	164.66	179.03	167.23	183.68	171.01
M. V. 4.86	2.88	10.06	5.91	6.38	6.08
P.E. 1.67	.99	3.47	2.03	2.20	2.09
O–C Diff. 12.04		11.80		12.67	
O–C P. E. 1.73		1.88		.85	
O–O Diff.	2.33		4.65		
O–O P. E.	2.55		3.31		
C–O Diff.		2.57		3.78	
C–O P. E.		1.48		1.69	

5. Reaction Time to Photometrically Equal Homogeneous Light Stimuli

Is reaction time to light conditioned only by the intensity of the stimulus, or is it influenced by the quality or wave length?—is a question both of theoretical interest and practical significance. That the latter is true is implied by Henmon[11] who by the method of discrimination reaction measured the time of perception of difference between pairs of colors. His experiments were in the main concerned with the red end of the spectrum, but other pairs of colors and black and white were also used as stimuli. Colored cards were used and no attempt was made to equate them for intensity. The following table gives a summary of the results from one reagent:

Stimuli Discriminated	*Reaction Time*
Black and White	196.6
Red and Green	203.2
Blue and Yellow	199.8
Red and Blue	212.1
Green and Yellow	211.7
Red and Yellow	217.7
Red and Orange	245.2
Red and Orange mixed with 25% Red	253.3
Red and Orange mixed with 50% Red	261.2
Red and Orange mixed with 75% Red	269.5

In discussing these results Henmon says, "It is hardly necessary to state that the colors were in each case rich, saturated colors. There is, however, the normal difference in brightness, and as in the previous experiments it is the opinion of the writer that the differences in time of perception are due in some degree to the differences in brightness in the case of red and blue. Of the two variables present in the stimuli the color tone should have given, if anything, a shorter time,[12] and therefore the reasonable assumption is that the brightness causes the difference."[13]

In the experiment reported here the apparatus and method were the same as in the previous experiments, the colored stimuli being

[11] The Time of Perception as a Measure of Differences in Sensations, by V. A. C. Henmon. *Archives of Psychology and Scientific Methods*, No. 8. July, 1906.

[12] By "shorter time" Henmon means that the reaction time, i.e., the discrimination time should have been shorter.

[13] Op. cit., page 37.

obtained by placing gelatine filters between the source of light and the mirror. The filters were furnished by the Research Laboratory of the Eastman Kodak Company and the light transmitted by them was as nearly monochromatic as it was possible to obtain by means of gelatine filters. They were equated with a standard flicker photometer at the Electrical Testing Laboratories, New York City, the source of light used in the photometer having been matched with the light of the lamp used as a source during the experiment. Then the relative distances at which the lights were photometrically equal were obtained by varying the distance of the mirror from the screen, these distances being relatively the same as the readings of the photometer scale.[14]

When photometrically equal the red, green and blue were rich, saturated colors, only the yellow being affected in color tone and this was described by the reagents as being "gold color." A neutral filter was also used. Described in terms of wave length the filters were as follows:

Green	560–510
Blue	510–360
Red	700–650
Yellow	700–500

Two reagents were employed, the procedure being as follows: Reagent G's reactions were taken to the series twice, each series being done in two periods, ten reactions being taken to each stimulus and the stimuli were mingled as in the previous experiments. Then reagent N was employed, the experiment being done once. The results are given in Tables XII and XII a, XIII and XIII–a and XIV and XIV a. Inspection of the tables shows that the differences are small and unreliable and in each case the order of quickness is different, being as follows:

[14] A discussion of the relative merits of different methods of photometry is beyond the scope of the present investigation. The accuracy of the various methods together with the experimental evidence is well stated in the following.

On the Measurement of Visual Stimulation Intensities, by L. T. Troland, *Journ. of Exper. Psychology*, Vol. II, No. 1, February, 1917.

A preliminary Study of the Deficiencies of the Method of Flicker for the Photometry of Lights of Different Colors, by C. E. Bruce and Gertrude Rand, *The Psychological Review*, Vol. XXII, No. 1, January, 1915.

	Green	*Blue*	*White*	*Red*	*Yellow*
G	4	5	2	3	1
	2	4	1	5	3
N	3	1	4	5	2

Individual differences in the perception of differences in brightness and differences due to the action time of the retina, if such are operative here seem to be obscured by the error of observation and the results seem to justify the conclusion that the time of reaction is not conditioned by the wave length of the stimulus.

TABLE XII

Reagent G—Colors

Green Average M. V.	*Blue* Average M.V.	*White* Average M.V.	*Red* Average M.V.	*Yellow* Average M.V.
159.5	159.1	168.8	173.1	159.6
4.3	5.7	8.2	4.2	6.0
168.2	168.1	165.1	160.1	171.2
7.4	7.3	6.7	5.9	8.8
168.0	169.7	176.9	172.0	166.8
7.0	4.5	11.9	7.7	5.4
169.3	170.1	168.4	173.6	159.6
2.9	7.2	4.2	9.0	8.2
177.3	178.6	159.4	185.7	175.0
5.7	8.4	5.0	8.2	11.0
162.8	167.3	168.0	160.5	161.0
6.4	8.5	7.8	6.5	8.2
173.0	173.1	166.6	178.4	174.2
6.8	8.3	4.4	6.3	3.2
167.1	176.3	167.2	162.3	175.2
10.8	4.3	4.6	7.3	5.0
178.4	168.8	166.6	173.9	182.1
4.2	12.0	14.4	6.3	11.3
168.0	170.8	171.9	166.3	172.7
6.8	5.4	8.3	6.5	7.1
Av. 169.16	170.19	167.89	170.59	169.74
M. V. 4.27	2.92	2.91	6.53	6.39
P. E. 1.14	.77	.77	1.74	1.70

TABLE XII–a

Reagent G

White	*Green*	*Yellow*	*Blue*	*Red*
167.89	169.16	169.74	170.19	170.59
Differences	1.27	1.85	2.30	2.70
P. E.	1.54	1.82	1.86	1.77

TABLE XIII

Reagent G—Colors

Green Average M. V.	*Blue Average M. V.*	*White Average M. V.*	*Red Average M. V.*	*Yellow Average M. V.*
162.5	172.8	168.2	164.3	166.5
8.40	10.80	13.28	11.36	12.20
177.7	176.6	172.0	181.9	191.7
9.44	10.40	6.80	13.10	13.70
188.6	186.3	175.7	177.1	178.3
9.08	12.46	10.70	6.90	18.04
189.9	194.4	188.0	188.8	176.8
12.12	13.00	5.20	7.44	11.00
186.2	172.3	179.9	175.8	178.1
12.20	7.84	7.88	7.44	12.12
178.9	173.2	172.9	185.7	168.9
6.14	12.60	10.30	5.70	8.68
174.1	182.2	182.2	175.8	175.8
4.59	6.96	7.30	7.84	8.56
178.3	175.1	177.9	181.0	178.3
5.50	4.50	4.70	8.60	5.56
178.2	179.7	179.7	177.1	178.8
5.00	5.44	4.04	2.68	5.60
180.4	187.4	187.9	182.3	186.1
4.28	8.24	4.08	2.64	4.50
Av. 179.480	180.000	178.430	178.980	177.930
M. V. 5.43	5.18	5.09	4.96	4.74
P. E. 1.44	1.38	1.35	1.32	1.26

TABLE XIII–a

Reagent G

Yellow	*White*	*Red*	*Green*	*Blue*
177.93	178.43	178.98	179.48	180.00
Differences	.50	.55	.50	.52
P. E.	1.21	1.20	1.01	1.39

TABLE XIV

Reagent N—Colors

Green Average M. V.	*Blue Average M.V.*	*White Average M.V.*	*Red Average M.V.*	*Yellow Average M.V.*
160.8	173.2	168.70	168.5	172.3
6.5	8.8	6.1	7.9	7.1
168.9	167.7	163.8	163.6	166.0
5.0	7.7	4.6	8.0	5.4
174.3	160.8	168.9	173.2	171.6
9.9	7.2	5.5	7.2	6.0
174.5	178.8	182.4	175.7	178.1
8.3	13.7	10.2	11.7	9.1
183.4	185.7	168.7	183.0	175.5
11.0	7.7	6.9	8.2	10.1
204.7	193.7	198.2	204.9	196.6
7.3	9.9	6.2	8.5	9.2
162.6	165.5	179.3	190.1	180.7
8.3	7.7	8.9	6.7	9.7
166.4	165.2	170.8	167.6	163.9
6.6	3.8	4.0	5.6	6.7
159.5	156.0	164.2	165.1	158.4
4.8	7.6	3.6	5.3	5.3
173.3	168.5	169.9	170.8	159.8
7.8	6.8	2.5	6.6	7.6
Av. 172.84	171.51	173.49	176.25	172.29
M. V. 9.20	9.07	7.88	9.85	8.35
P. E. 2.45	2.42	2.10	2.62	2.22

TABLE XIV–a

Reagent N

Blue	*Yellow*	*Green*	*White*	*Red*
171.51	172.29	172.84	173.49	176.25
Difference	.78	.55	.65	2.76
P. E.	1.25	1.77	1.87	.92

6. Conclusions

The results obtained in these experiments seem to justify the following conclusions:

1. That reaction time to light stimuli varies inversely and arithmetically as the intensity of the stimulus varies geometrically and that the variation in reaction time is to some degree proportional to the variation of the intensity of the stimulus.

2. That reaction time to cessation of light stimuli also varies arithmetically and inversely as the intensity of the stimulus varies geometrically, the increase or decrease of reaction time with decrease or increase of intensity of the stimulus being less than that of the increase or decrease in reaction time to onset of the stimulus.

3. That there is a relatively large difference between the reaction time to onset of the stimulus and cessation of the stimulus, the latter being quicker, and this difference becomes greater as the intensity of the stimulus decreases.

4. That reaction time to light is not conditioned by the wave length of the stimulus. In the light of what is known in regard to the action time[15] of the retina, this result was not entirely to be expected, but if any difference in time of perception is due to this factor it apparently is so small that it is obscured by the error of observation.

Attention is called to the fact that in the tables of results a measure of reliability, the probable error, is given for every final average and every difference, the probable error of the latter being mathematically the same as that of the average, i. e., a probable error of the average difference. When negative differences, i. e., differences in the opposite direction from that expected and from that found in other cases occurred, they were explicable in terms of relative differences of intensity of stimuli or variability of the reagents' performance due to lack of practice or individual differences. That some of the differences found are statistically unreliable is fully conceded, but this is not to be taken as an implication that they are not real differences.

Two explanations of differences in reaction time due to differences in stimulation are current, the inertia of the end organs and the resistance of the synapses[16] The former conception is invoked to

[15] "The Lag of Visual Sensation in its Relation to Wave Length and Intensity of Light," by M. A. Bills, *Psychological Monographs*, Vol. XXVIII, No. 5.

[16] Sherrington—The Integrative Action of the Nervous System, 1906.

explain such differences in reaction time as are found to exist between reaction time to light and reaction time to sound.[17] This might also be conceived of as an explanation of differences in reaction time to different intensities of light stimuli, the greater the intensity the more quickly would the inertia of the retina be overcome and vice versa.

Consider the results of the experiment on reaction time to onset of light stimuli of different intensities. It has been shown by Exner that the time of the rise of the visual sensation increases in arithmetical progression as the intensity of the white light stimulus decreases in geometrical progression.[18] This description of the reaction of the retina to different intensities is in exact agreement with the present findings in regard to reaction time to white light. But investigations of the rise of visual sensations when monochromatic light stimuli are used show that the action time of the retina differs with the wave length of the stimuli when the latter are photometrically equal. In the last experiment reported here it was shown that the reaction time was not conditioned by the wave length of the stimuli. Obviously then the differences in reaction time to different intensities of stimuli cannot be explained as due to the action time of the retina.

That the delay is not in the transmission of the nerve impulse through the nerve fibers is shown by the experimental findings of many investigators, who all agree that the rate of transmission of the nerve impulse is independent of the strength of the stimulus.[19]

There remains then but one part of the nervous arc in which the delay may occur, namely, the synapse. That this is the locus of the delay is maintained by no less an authority than Sherrington, who says:

> "The speed of travel of nervous impulses along nerve-trunks is fairly known. On the not improbable assumption that their velocity along the myelinate fibers of the white tracts of the central nervous system is about the same as along the myelinate fibers of nerve trunks, the latent period of reflex-actions of moderate intensity is obviously greater than can be accounted

[17] Ladd & Woodworth—Elements of Physiological Psychology, 1911.
[18] Bills. Op. cit.
[19] Bayliss—Principles of General Psychology. 1915.

for by travel along such conductors of the same length as the reflex-arc itself. The delay in speed occurs whenever the impluses pass through gray matter. . . . The delay in the gray matter may be conceivably due to slower conduction in the minute, branched, and more diffuse conducting elements . . . found there; or it may be referable to a fresh kind of transmission coming in there, a process of transmission different in nature to conduction along nerve fibers. The neurone itself is visibly a continuum from end to end, but continuity, as said above, fails to be demonstrable where neurone meets neurone—at the synapse. There a different kind of transmission may occur. The delay in the gray matter may be referable, therefore, to the transmission at the synapse."[20]

Can the results obtained in the experiment on reaction time to cessation of stimuli be explained in terms of nerve conduction and resistance at the synapses? Woodrow in discussing his results states that he is unable to accept this explanation and in lieu of it postulates "a central system of energies, the balance of which may be upset by either an increase or decrease of activity in any part of the system."[21]

The apparent paradox of reacting to cessation of stimuli vanishes when one distinguishes between the physical stimulus and the physiological stimulus.

In the case of reactions to visual stimuli the first is vibrations of the ether and the second is the photo-chemical action of the retina. In current color theories the chemical substances of the retina are conceived of as in a state of equilibrium and stimulation consists in disturbances of this equilibrium resulting in changes in either direction, both of which excite nerve fibers. Now there is no inherent difficulty in conceiving of cessation of light stimuli as the cause of changes in the chemical action of the retina and so as the initiator of nerve impulses. One other result of the experiments seems to call for an explanation, namely, the fact that cessation reactions were quicker than onset reactions. The explanation of this is to be found in the conditions of the experiments. When reactions to the onset of the stimulus were being taken the reagent

[20] Op. cit., p. 21.
[21] Op. cit., p. 451.

sat before a screen which was dimly lighted where the stimulus was to appear. When reactions to cessation were being taken he fixiated the hole in the screen with the stimulus before him. Obviously the latter condition was more favorable to a high degree of attention, an efficient "accommodation or adjustment of the sensory organs."[22]

[22] James, Principles of Psychology, Vol. I, p. 434.

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